FOLDED AUSTRALITE BOWL FROM PORT CAMPBELL DISTRICT, VICTORIA, AUSTRALIA

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Abstract

A folded australite (tektite) from Goudie's Lookout, Victoria, was a thin oval or boat-shaped bowl of approximate dimensions 17 x 8 x 4 mm. It developed from a small, elongated primary body by aerodynamic processes during passage at hypersonic speeds through the earth's atmosphere, but while still hot and plastic, the sides folded backward and were fused together. Peculiarities of shape arose from the excessive length of hinge relative to the perimeter of the bowl. No impact damage resulted at the earth's surface but subsequent terrestrial weathering effects are evident.

Introduction

An australite specimen in the collection of the National Museum of Victoria (E 7852) was formerly No. 1257 in the private collection of the late Dr George Baker. It was found in March 1951 in a borrow pit east of Goudie's Lookout on the coast of Victoria, 3 km south of east from Port Campbell.

The specimen is of rare morphological type, the final shaping process being complete folding collapse. The partial folding of small australites is not rare. A selected group of 26 specimens from the Eastern Goldfields of Western Australia presently being examined includes seven specimens showing stages of folding ranging from early beginnings to half completed. Rarely, the folding of small round or oval australites progressed to the stage when the opposing sides made contact at the edges, which were fused together. The Goudie's Lookout specimen is the only one known to me in which folding collapse was so complete that the sides flattened against each other and fused together over almost their entire areas.

In conversation with the writer, the late Dr Baker referred to the specimen as his "pastie" australite, a most apt description of the form and the role of folding in its development.

Description of folded australite

The australite has a hinge at one edge (lower profile of Pl. 9, Fig. A) with the ends of the hinge slightly reflexed from the main body as two 'ears'. The margins of the two folded sides have the form of two gently curved lips (top of same illustration) with one lip slightly curled over the other. The lips are closely pressed together in the middle, but are slightly parted at the 'ends of the mouth'. The form is corrugated across the length with a strong kink near each end and a more gentle curve between (Pl. 9, Figs. B and D).

The overall dimensions between tangents to the irregularly curved shape and in the conventional sequence (length and width in planes normal to the line of flight, depth parallel to the line of flight) are 19·5 x 3·4 x 6·7 mm. The foregoing statement assumes that flight orientation was momentarily maintained after folding occurred. The thickness in the central, less distorted part of the specimen is in the range 2·0-2·3 mm. The glass was therefore generally a little more than 1 mm thick prior to folding.

The mass of the australite is 0·4056 g and the specific gravity 2·428 ± 0·002 (three determinations by loss of weight in toluene at temperatures 26·2-27·0°C).

A group of bubbles trapped between the two folded halves of the specimen (Fig. 1A) is visible macroscopically. The largest bubbles have observable dimensions 2·7 x 0·45 mm and 2·6 x 0·8 mm; they may be considerably flattened in the third dimension. The pattern suggests a curving channel of escape of gas, some of which was trapped below the closed lips and forced to spread laterally beneath them as the sides pressed together. The bubbles have a total sectional area equal to about 4% of the sides.

A few bubbles of a smaller order of size (generally <0·1 mm) are visible microscopically within the glass. They are distinguishable from small bubbles of the previous group, which is at a depth of about 1 mm, by using a microscope with measurable working distance, focussing first on the surface of the specimen and then downward to the edge of the bubble.

The specimen is uniformly translucent, i.e. there is no indication of a core.

Lechatelierite inclusions are present in about usual abundance. They are very variable in form—narrow or stout, straight or curved, rounded or ovoid, occasionally of complexly curved shape—and they generally have dimensions in the range 20-140 μ m.

Examination of the liquid-immersed specimen between crossed polars shows distinctly birefringent bands adjoining the hinge and the lips, and very generally distributed, elongate, wispy areas of much weaker birefringence elsewhere. All of these extinguish parallel or sub-parallel to the hinge. The band along the hinge is understandable as the result of residual strain from the stretching of the glass around the hinge, but it is necessary to accept a later conclusion of this study to understand the generally distributed, weaker, residual strain responsible for birefringence elsewhere. The two folded sides of the specimen were initially convex outward and they were flattened against each other by the folding collapse. They have therefore been bent, but in the opposite sense to the main hinge, the bending having evidently been concentrated upon numerous sub-parallel, but locally divergent, minor axes.

The surface of the specimen is abundantly pitted. The largest pits have diameter 0·4 mm, but most are much smaller. The surface of the australite is the anterior surface of oriented flight together with the edge of the lip. The pits are not therefore bubble pits from the primary degassing and it is rare for bubble pits related to secondary reheating to be found except on protected surfaces of secondary glass—e.g. the rear surfaces of flanges. Most pits, if not all, can be attributed to solution etching by the chemicals of soil water or other terrestrial agencies since the australite arrived on the earth's surface. Schlieren of slightly different chemical compositions are also evident as the result of differential etching, especially towards the 'ears' of the specimen. A small area of fragile scaly surface has been developed, and extraneous material is firmly embedded within it.

Reconstruction of pre-folding form

For the purposes of reconstruction, the following additional measurements were made:—

Length of hinge (lower profile of Fig. 1B), the pre-folding 'length'	21·1 mm
From outer edge of the lower lip as seen in Fig. 1B around the hinge to the outer edge of overhanging lip, i.e. the flattened out, pre-folding 'width'	13·3 mm
Length of outer edge of lip, the pre-folding perimeter	42·5 mm

If the pre-folding form had been simply an oval plate of dimensions 21·1 x 13·3 mm, it would have had perimeter about 54·7 mm (calculated as an ellipse) and could have folded with a straight line hinge; the available perimeter was deficient about 22%. The presence of the 'ears' and the crumpling along the length also indicate the deficiency of perimeter—or stated otherwise, the excessive length of hinge—for such a simple type of folding.

Clearly, the form was not a plate but a bowl in which the 21·1 mm and 13·3 mm were the lengths of the outer curves of the longitudinal and cross sections respectively. The three measured lengths would be in correct ratio in a bowl of appropriate proportions.

The lip of a bowl which has suffered no folding is generally in a plane normal to the line of flight, i.e. the depth dimension is common to longitudinal and cross sections, each of which usually approximates to a semi-ellipse. Provided that the length/width ratio (L/W) was not too large, the perimeter of the bowl would also have approximated to an ellipse.

Using the measured lengths above and the formula for perimeter of the ellipse, three simultaneous equations were set up, each equation including two semi-axes of the elliptical sections of the bowl. Their solution gave the dimensions of the bowl as 17·7 x 8·6 x 4·15 mm. The L/W was 2·06.

Fenner (1940, p. 312) has defined the arbitrary L/W limits of the increasingly elongated series from broad ovals through narrow ovals to boat forms as $> 1 \leqslant 4/3$, $> 4/3 \leqslant 2$,

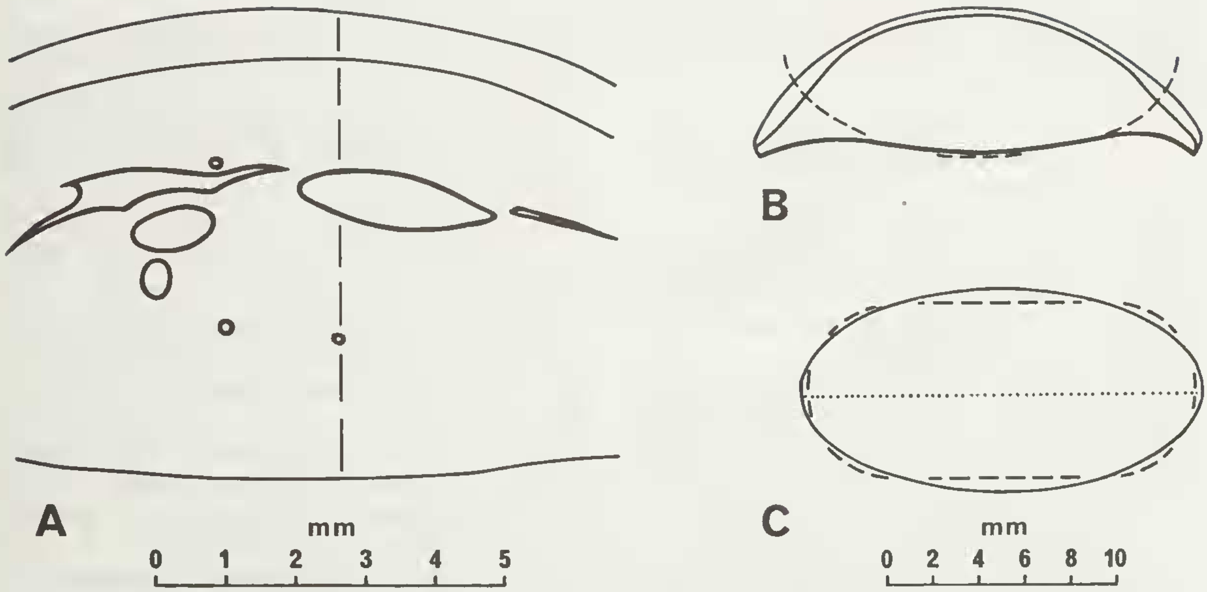

Fig. 1—A, Group of bubbles trapped between sides of folded australite near mid-line (broken line) as seen in side elevation. Hinge and direction of flight towards bottom of page. B, Sketch of folded australite showing site and form of hinge before folding (broken line) and hinge after folding (heavy line of lower profile). C, Plan views looking down line of flight of two alternative reconstructions of the bowl which was parental to the folded australite. Oval (solid line), boat shape (broken line), future hinge fractionally off main axis (dotted line). Scale at lower right applies to B and C.

and > 2 respectively. In an uncompleted study of the degree of elongation at which oval forms are transitional into parallel-sided forms, I have found that 67 out of 72 parallel-sided specimens (93%) have L/W > 2, and that 111 out of 131 oval specimens (85%) have L/W $\leqslant 2$. The study includes Fenner's narrow ovals only, but if broad ovals were also included, the percentage of ovals with L/W $\leqslant 2$ would certainly exceed 90%. Fenner's arbitrary limiting figure appears to be well chosen since there are about equal probabilities that a specimen with L/W 2 will be oval in shape or parallel-sided. It is therefore probable that a form with L/W > 2 would be parallel-sided rather than oval.

Consideration of the parallel-sided form does not introduce a fourth variable because the ends of such forms are closely semicircular. Thus the equation for perimeter of the bowl is

$$2\pi b + 4(a - b) = 42{\cdot}5$$

where *a* and *b* are the same symbols for semilength and semiwidth as were used for the oval bowl. The other equations are unchanged and their solution yields the dimensions 16·94 x 7·60 x 4·66 mm, with 9·3 mm lengths of parallel sides. Such a bowl would be closely similar in form and proportions to a boat-shaped bowl from Port Campbell district described and figured by Baker (1963, No. 28), but about $1\frac{1}{2}$ times as large. The alternative solutions are:—

oval bowl	18 x $8\frac{1}{2}$ x 4 mm	L/W 2·1
boat-shaped bowl	17 x $7\frac{1}{2}$ x $4\frac{1}{2}$ mm	L/W 2·2

The outlines of the lips are very gently curved as in ovals, but originally straight sides may have been bent slightly as a result of folding of the bowl. The gaping at the 'ends of the mouth' is not a feature favouring the more open-ended boat shape. The same gaping is present in specimens which were initially round or oval. The maximum angle of folding (180°) would be necessary at the 'ends of the mouth' to bring the sides into contact. The present form of the specimen does not allow confident choice between the oval and boat shapes, which differ little in plan view (Fig. 1C).

The glass thickness towards the centre of the bowl was about 1 mm. The central cavity was therefore 3-3½ mm deep.

Mechanics of folding

The following appear pertinent to a consideration of the mechanics of folding:—

(a) About the time when atmospheric shaping processes were complete, a form only 1 mm thick would be hot throughout and therefore capable of folding plastically.

(b) The two folding halves were convex outward in the general style of a hinged bivalve. Contact would be made first at the lips and, with further pressure, would be established inward from both the lips and the hinge.

(c) Because the hinge was a curved line, folding would tend to straighten it, the ends of the hinge moving outward and downward. (Visualize a trough being folded upward on a transverse hinge; the sides bulge as the hinge straightens to the horizontal.)

(d) The surplus length of hinge, estimated as about 7 mm, would need to be accommodated in some way if the sides were forced into close contact over most of their areas.

Development and history of folded specimen

A small, elongated australite primary body developed bowl shape during passage through the earth's atmosphere at hypersonic speeds (Baker 1958, pp. 380-382). The bowl was oval or boat-shaped, of approximate dimensions 17 x 8 x 4 mm, but the glass of the frontal region was only about 1 mm thick and hot throughout. After active shaping ceased, the temperature fell, and especially rapidly when the speed was reduced to the stage that heat generation failed to equal heat losses. Late in the stage of active shaping when the form was essentially complete, or early in the succeeding stage while the temperature was still high, the bowl collapsed suddenly by the sides folding upwards (i.e. backward from the direction of flight) on a hinge which was approximately coincident with the 'keel' of the bowl. The lips flattened against each other and adhered firmly. While flight orientation was momentarily maintained, air pressure forced the side closer together, contact proceeding inward from the lips and from the hinge. Most of the 'dead air' posterior to the bowl escaped before contact was established or through the 'corners of the mouth', but some was trapped and separated into a trail of bubbles. The hinge was straightened by the folding and because the sides made firm contact over about 96% of their areas, the surplus length of hinge was accommodated by being bent further downward as 'ears' and by some crumpling along the length. Momentarily later, the now misshapen australite lost its fixed orientation relative to the line of flight and tumbled irregularly, but it remained hot long enough for the sides to be firmly fused together. It reached the earth's surface at low velocity as a cold body and suffered no recognized damage on impact. Terrestrial agencies have since developed some pits and have etched schlieren differentially and lightly, but the state of preservation would be regarded as unusually high on any standards except those of the uniquely well-preserved Port Campbell australites.

Acknowledgements

I thank the Council and Director (Mr J. McNally) of the National Museum of Victoria and the Curator of Minerals (Dr W. D. Birch) for allowing me to examine the folded australite specimen, and I take the opportunity of recording my indebtedness to the late Dr George Baker, whose usual kindly and meticulous criticism of my manuscripts was sadly missed on this occasion.

References

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Description of Plate 9

FOLDED AUSTRALITE BOWL

Four views of folded australite bowl as specimen is rolled over from top towards bottom of page.

Figure A—Side elevation, hinge of folding at bottom, lips at top. Direction of flight towards bottom of page.

Figure B—Lips. Note folding along the length.

Figure C—Opposite side to A, direction of flight towards top of page.

Figure D—Hinge area.

(Photos A-D by Mr M. Joyce, Kalgoorlie.)